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## TRANSPARENT ARMOR: A LITERATURE SURVEY



### TECHNICAL REPORT

By

**Robert E. Ofner**

July 1968

SCIENCE & TECHNOLOGY LABORATORY  
RESEARCH & ENGINEERING DIRECTORATE

U. S. ARMY WEAPONS COMMAND

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## ABSTRACT

One hundred and thirty three references to published work pertaining to transparent armor for use in the vision ports of Army ground vehicles or in aircraft enclosures are listed under ten categories, as follows: state of the art; glass; plastics; glass-plastic; single crystal ceramics; dynamic properties of polymers; fiber optics; vision blocks; military specifications, handbooks and drawings; bibliographies.

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## OBJECTIVE

To survey the literature on transparent armor and to prepare a bibliography of those publications which best describe important achievements of past years, the current state of the art and the most promising approaches to the development of minimum weight armor having an optimum balance between optical clarity and resistance to projectiles.

## BACKGROUND

The combat effectiveness of Army land and air borne vehicles is largely dependent upon the ability of the crews to perform the visual observations required by their missions, without undue danger from enemy gun fire. Any material which provides both the required visibility and the ballistic protection is termed "transparent armor".

Army needs for transparent armor are largely limited to two types of applications, the enclosures of aircraft and the vision ports of ground vehicles. Enclosures are canopies, windows or windshields while vision ports are best exemplified by the glass blocks in the cupulas of armored vehicles. Another class of item usually associated with transparent armor is the sighting device, such as the periscope, telescope or range finder. Here, of course, emphasis is placed on the need for unimpaired vision, with ballistic protection as a secondary requirement.

Transparent armor, combining optimum visibility and resistance to projectile penetration, has been an exceedingly difficult item to develop, largely because of the inherent incompatibility of these properties in available materials. Until shortly after World War II, transparent armor usually consisted of "safety" or "bullet proof" glass, two or more panels of glass laminated with a thin, flexible plastic interlayer. Although glass has the best optical properties of all known materials, it is brittle and has little tendency to defeat projectiles unless it is used in thicknesses so large that vision is impaired and the weight and volume of the armor become unacceptable.

The post war era brought forth a proliferation of new, commercially available plastics and elastomers, several with good optical clarity and some with excellent resistance to impact and projectile penetration. A large amount of research was initiated to make use of these new polymers in glass-plastic composite armor or in all-plastic laminated armor. The use of the new, transparent rubbers as interlayers was also investigated. These efforts are continuing today and significant reductions in the weight of "bullet proof" glass have been achieved without loss of ballistic protection.

The influx of plastics and rubbers into a field heretofore served primarily by glass, stimulated a large effort by major glass manufacturers to improve their product. Stronger, higher moduli glasses with improved clarity and better resistance to aging have resulted. Fiber optics

may be of value here. This research effort is also continuing.

In about 1963, the U. S. Army Natick Laboratories, in conjunction with the Army Materials Research Agency (now the Army Materials and Mechanics Research Center), initiated efforts with industry toward the development of single crystal ceramics. Details of this work are classified but the "synthetic sapphire" holds much promise for the future of lightweight transparent armor.

The many polymers synthesized in recent years have prompted the development of new analytical tools and techniques for determining their properties. A vast amount of research involving these analytical methods is currently in progress to investigate the photoelastic properties of polymers, to conduct dynamic stress analyses on polymers as a function of their structure. A more fundamental understanding of these properties and responses of materials is necessary to insure continued advances in the development of lightweight, transparent armor.

This survey was prepared for use by the Army designer of transparent armor, with the hope that by examining judicious selections from the referenced reports and papers, he might become familiar with the state of the art and with the anticipated developments of the future, thereby increasing his capability to provide the Army with the best transparent armor available.

#### Future Efforts by the Army Weapons Command (AWC)

Bearing in mind that AWC's primary interest in transparent armor lies with vision blocks and fire control sighting devices, three approaches appear to be applicable to the future improvement of these items, namely, the improvement of the all-polymeric (plastic or plastic-rubber) armor; the development of single crystal ceramic armor and the use of fiber optics.

Although plastic armor has already been developed with improved ballistic protection over that obtainable with the same weight and thickness of safety glass, much work remains to be done. New, commercially available rubbers and plastics need to be evaluated as anti-spall materials and as interlayers; improved resistance to aging, discoloration and scratching is needed in the polymeric composite armor; improved resistance to temperature extremes is required and composite armor made of materials having like coefficients of thermal expansion is required. Program

funding in these areas of endeavor should be considered by AWC.

Single crystal ceramics are currently under development through the joint efforts of the Army Natick Laboratories, the Army Materials and Mechanics Research Center and private industry. This work should be monitored closely by AWC in order that the knowledge required to use these ceramic materials in armor might be available at such time as they become economically competitive with more conventional materials. The cost of fabricating the single crystal materials is exorbitant at this time.

The techniques of fiber optics need to be investigated, especially in relation to sighting devices. Fiber optics may provide novel methods of obtaining external visibility from the interior of armored vehicle. Funding of programs in this area is recommended.

#### Sources for the Bibliography

No bibliography on transparent armor was known to the author at the onset of this survey. Accordingly, a "Report Bibliography on Transparent Armor" was requested from the Defense Documentation Center (DDC). Thirty seven of the fifty military reports abstracted in the DDC bibliography were applicable to transparent armor and were obtained from DDC. Many of these reports contained references to other reports, books and published articles, including a few bibliographies on armor. These were obtained whenever possible or the references were listed when applicable. No open literature was surveyed because the majority of publications on transparent armor are classified. Mr. A. Alesi of the Natick Laboratories and Mr. G. Parsons of Army Materials and Mechanics Research Center were helpful in furnishing references to military reports.



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Army Weapons Command,  
Attn: STL,  
Rock Island,  
Arsenal, Ill.

USAWC notice,  
11 Jun 69